Smart Materials and Structures
Highlights of 2013

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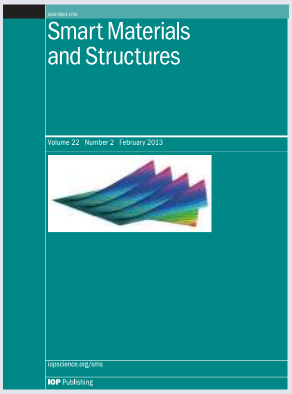

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Dear Colleague,

I am delighted to present the latest collection of abstracts from highlighted articles published in 2013 in *Smart Materials and Structures,* showcasing the exciting research that we present across all areas of smart materials, structures and systems.

The articles were chosen based on their popularity with our readers, the Editorial Board and international press, and will be free to read online until the end of the year.

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Natasha Leeper
Publisher
Smart Materials and Structures

Great science deserves great recognition

A turtle-like swimming robot using a smart soft composite (SSC) structure

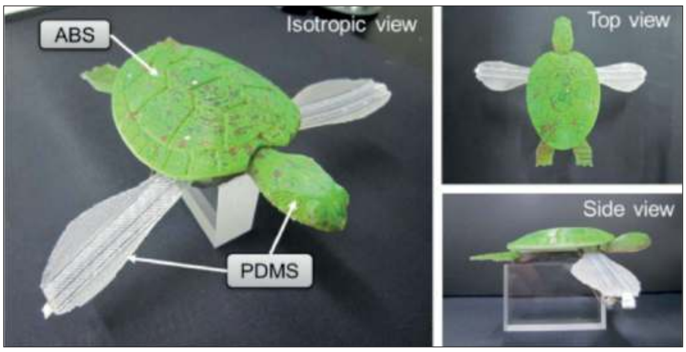
Hyung-Jung Kim[1], Sung-Hyuk Song[1] and Sung-Hoon Ahn[1,2]

[1] School of Mechanical and Aerospace Engineering, Seoul National University, Seoul, Korea

[2] Institute of Advanced Machinery and Design, Seoul National University, Seoul, Korea

Abstract
This paper describes the development of a biomimetic swimming robot based on the locomotion of a marine turtle. To realize the smooth, soft flapping motions of this type of turtle, a novel actuator was also developed, using a smart soft composite (SSC) structure that can generate bending and twisting motions in a simple, lightweight structure. The SSC structure is a composite consisting of an active component to generate the actuation force, a passive component to determine the twisting angle of the structure, and a matrix to combine the components. The motion of such a structure can be designed by specifying the angle between a filament of the scaffold structure and a shape-memory alloy (SMA) wire. The bending and twisting motion of the SSC structure is explained in terms of classical laminate theory, and cross-ply and angled-ply structures were fabricated to evaluate its motion. Finally, the turtle-like motion of a swimming robot was realized by employing a specially designed SSC structure. To mimic the posterior positive twisting angle of a turtle's flipper during the upstroke, the SMA wire on the upper side was offset, and a positive ply-angled scaffold was used. Likewise, for the anterior negative twisting angle of the flipper during the downstroke, an offset SMA wire on the lower side and a positive ply-angled scaffold were also required. The fabricated flipper's length is 64.3 mm and it realizes 55 mm bending and 24° twisting. The resulting robot achieved a swimming speed of 22.5 mm s^{-1}.

2013 *Smart Mater. Struct.* **22** 014007



Assembled turtle-like swimming robot.

In search of better electroactive polymer actuator materials: PPy versus PEDOT versus PEDOT–PPy composites

Rauno Temmer[1], Ali Maziz[2], Cédric Plesse[2], Alvo Aabloo[1], Frédéric Vidal[2] and Tarmo Tamm[1]

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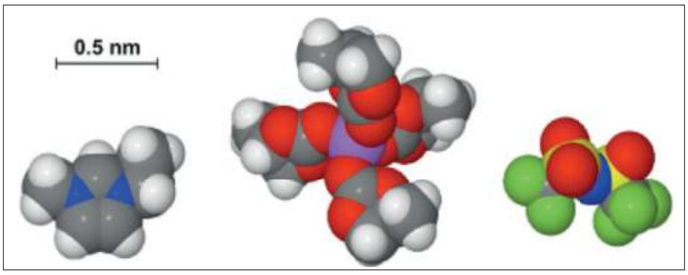
[2] Laboratoire de Physicochimie des Polymères et des Interfaces, Université de Cergy-Pontoise, France

Abstract
A comparative study of metal-free air-operated polypyrrole and PEDOT based trilayer actuators is presented. Actuators made of both pure and combined conducting polymers are considered. Trilayer bending actuators, synthesized in similar conditions, are characterized in terms of the structure, electrochemical and electro-chemo-mechanical properties. The characterization was carried out using two popular electrolytes: LiTFSI in propylene carbonate and a room-temperature ionic liquid EMIm TFSI. The results reveal that structure and actuation properties of the synthesized actuators depend on both the polymer chosen for the chemically synthesized electrode layer as well as the electrochemically synthesized working layer.

2013 *Smart Mater. Struct.* **22** 104006



Images of space-filling models of EMIm+, Li+ solvated with four PCs, and TFSI⁻, respectively.

Soft magnetorheological polymer gels with controllable rheological properties

Yangguang Xu, Xinglong Gong and Shouhu Xuan

CAS Key Laboratory of Mechanical Behavior and Design of Materials, University of Science and Technology of China, Hefei, People's Republic of China

Abstract
A series of magnetorheological (MR) gels consisting of plastic polyurethane matrix swollen by nonvolatile solvent in different weight fractions and carbonyl iron particles were prepared. Their magnetorheological properties, both under oscillatory and rotational shear rheometry, were systematically tested. The results demonstrate that except for the significant influence on the magnetorheological performance, the state of these MR gels can also be easily switched from solid-like (the solvent content is less than 10 wt%) to liquid-like (the solvent content exceeds 25 wt%) by adjusting the solvent content. The huge differences in magnetorheological properties of different MR gels (for example, the *G*′ of MR gels without solvent is three orders of magnitude larger than that of MR gels with 45 wt% of solvent in the absence of a magnetic field) and movements of iron particles in the presence of a magnetic field were analyzed, which are helpful in thoroughly understanding the mechanical–magnetic coupling mechanism between the magnetic particles and the polymer matrix and promoting the application of MR polymer gels. In addition, the stability of MR gels was also investigated. A gravity yield parameter was introduced to quantitatively describe the relationship between particle sedimentation and material characteristics. When the solvent content is lower than 25 wt% or the gravity yield parameter is larger than 0.865, the particle settling phenomenon can be effectively avoided.

2013 *Smart Mater. Struct.* **22** 075029

Electroelastic modeling and experimental validations of piezoelectric energy harvesting from broadband random vibrations of cantilevered bimorphs

S Zhao and A Erturk

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Abstract
We present electroelastic modeling, analytical and numerical solutions, and experimental validations of piezoelectric energy harvesting from broadband random vibrations. The modeling approach employed herein is based on a distributed-parameter electroelastic formulation to ensure that the effects of higher vibration modes are included, since broadband random vibrations, such as Gaussian white noise, might excite higher vibration modes. The goal is to predict the expected value of the power output and the mean-square shunted vibration response in terms of the given power spectral density (PSD) or time history of the random vibrational input. The analytical method is based on the PSD of random base excitation and distributed-parameter frequency response functions of the coupled voltage output and shunted vibration response. The first of the two numerical solution methods employs the Fourier series representation of the base acceleration history in an ordinary differential equation solver while the second method uses an Euler–Maruyama scheme to directly solve the resulting electroelastic stochastic differential equations. The analytical and numerical simulations are compared with several experiments for a brass-reinforced PZT-5H bimorph under different random excitation levels. The simulations exhibit very good agreement with the experimental measurements for a range of resistive electrical boundary conditions and input PSD levels. It is also shown that lightly damped higher vibration modes can alter the expected power curve under broadband random excitation. Therefore, the distributed-parameter modeling and solutions presented herein can be used as a more accurate alternative to the existing single-degree-of-freedom solutions for broadband random vibration energy harvesting.

2013 *Smart Mater. Struct.* **22** 015002

Hierarchical architecture of active knits

Julianna Abel, Jonathan Luntz and Diann Brei

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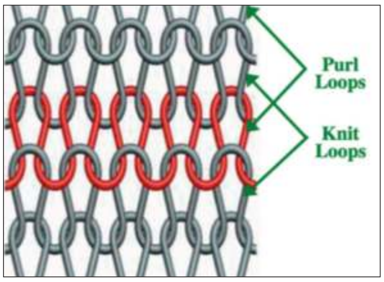
Abstract
Nature eloquently utilizes hierarchical structures to form the world around us. Applying the hierarchical architecture paradigm to smart materials can provide a basis for a new genre of actuators which produce complex actuation motions. One promising example of cellular architecture—active knits—provides complex three-dimensional distributed actuation motions with expanded operational performance through a hierarchically organized structure. The hierarchical structure arranges a single fiber of active material, such as shape memory alloys (SMAs), into a cellular network of interlacing adjacent loops according to a knitting grid. This paper defines a four-level hierarchical classification of knit structures: the basic knit loop, knit patterns, grid patterns, and restructured grids. Each level of the hierarchy provides increased architectural complexity, resulting in expanded kinematic actuation motions of active knits. The range of kinematic actuation motions are displayed through experimental examples of different SMA active knits. The results from this paper illustrate and classify the ways in which each level of the hierarchical knit architecture leverages the performance of the base smart material to generate unique actuation motions, providing necessary insight to best exploit this new actuation paradigm.

2013 *Smart Mater. Struct.* **22** 125001



Horizontally striped knit pattern—garter. The distributed contraction of garter is driven by the symmetric architecture. The front view 3D graphic of alternating courses of knit and purl loops.

Ferromagnetic shape memory flapper for remotely actuated propulsion systems

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[2] Department of Aerospace Engineering and Mechanics, University of Minnesota, Minneapolis, USA

[3] Present address: GRAB Lab, Yale University, New Haven, USA

Abstract
Generating propulsion with small-scale devices is a major challenge due to both the domination of viscous forces at low Reynolds numbers as well as the small relative stroke length of traditional actuators. Ferromagnetic shape memory materials are good candidates for such devices as they exhibit a unique combination of large strains and fast responses, and can be remotely activated by magnetic fields. This paper presents the design, analysis, and realization of a novel NiMnGa shear actuation method, which is especially suitable for small-scale fluid propulsion. A fluid mechanics analysis shows that the two key parameters for powerful propulsion are the engineering shear strain and twin boundary velocity. Using high-speed photography, we directly measure both parameters under an alternating magnetic field. Reynolds numbers in the inertial flow regime (>700) are evaluated. Measurements of the transient thrust show values up to 40 mN, significantly higher than biological equivalents. This work paves the way for new remotely activated and controlled propulsion for untethered micro-scale robots.

2013 *Smart Mater. Struct.* **22** 085030

Improving the critical speeds of high-speed trains using magnetorheological technology

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[1] School of Mechanical, Material and Mechatronic Engineering, University of Wollongong, Australia

[2] School of Instrument Science and Opto-electronics Engineering, HeFei University of Technology, People's Republic of China

[3] School of Electrical, Computer and Telecommunications Engineering, University of Wollongong, Australia

[4] Department of Civil and Structural Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Abstract
With the rapid development of high-speed railways, vibration control for maintaining stability, passenger comfort, and safety has become an important area of research. In order to investigate the mechanism of train vibration, the critical speeds of various DOFs with respect to suspension stiffness and damping are first calculated and analyzed based on its dynamic equations. Then, the sensitivity of the critical speed is studied by analyzing the influence of different suspension parameters. On the basis of these analyses, a conclusion is drawn that secondary lateral damping is the most sensitive suspension damper. Subsequently, the secondary lateral dampers are replaced with magnetorheological fluid (MRF) dampers. Finally, a high-speed train model with MRF dampers is simulated by a combined ADAMS and MATLAB simulation and tested in a roller rig test platform to investigate the mechanism of how the MRF damper affects the train's stability and critical speed. The results show that the semi-active suspension installed with MRF dampers substantially improves the stability and critical speed of the train.

2013 *Smart Mater. Struct.* **22** 115012

High-speed railway vehicle.

All-silicone prestrain-locked interpenetrating polymer network elastomers: free-standing silicone artificial muscles with improved performance and robustness

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Abstract
We present a novel all-silicone prestrain-locked interpenetrating polymer network (all-S-IPN) elastomer for use as a muscle-like actuator. The elastomer is fabricated using a combination of two silicones: a soft room temperature vulcanizing (RTV) silicone that serves as the host elastomer matrix, and a more rigid high temperature vulcanizing (HTV) silicone that acts to preserve the prestrain in the host network. In our novel S-IPN fabrication procedure we co-dissolve the RTV and HTV silicones in a common solvent, cast thin films, and allow the RTV silicone to cure before applying prestrain and finally curing the HTV silicone to lock in the prestrain. The free-standing prestrain-locked silicones show a performance improvement over standard free-standing silicone films, with a linear strain of 25% and an area strain of 45% when tested in a diaphragm configuration. We show that the process can also be used to improve electrode adhesion and stability as well as improve the interlayer adhesion in multilayer actuators. We demonstrate that, when coupled with carbon nanotube electrodes, fault-tolerance through self-clearing can be observed. We use the fault-tolerance and improved interlayer adhesion to demonstrate stable long-life (>30 000 cycles at >20% strain) actuation and repeated high-performance actuation (>500 cycles at ~40% strain) of prestrained free-standing multilayer actuators driving a load.

2013 *Smart Mater. Struct.* **22** 055022

A review of the recent research on vibration energy harvesting via bistable systems

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Abstract
The investigation of the conversion of vibrational energy into electrical power has become a major field of research. In recent years, bistable energy harvesting devices have attracted significant attention due to some of their unique features. Through a snap-through action, bistable systems transition from one stable state to the other, which could cause large amplitude motion and dramatically increase power generation. Due to their nonlinear characteristics, such devices may be effective across a broad-frequency bandwidth. Consequently, a rapid engagement of research has been undertaken to understand bistable electromechanical dynamics and to utilize the insight for the development of improved designs. This paper reviews, consolidates, and reports on the major efforts and findings documented in the literature. A common analytical framework for bistable electromechanical dynamics is presented, the principal results are provided, the wide variety of bistable energy harvesters are described, and some remaining challenges and proposed solutions are summarized.

2013 *Smart Mater. Struct.* **22** 023001

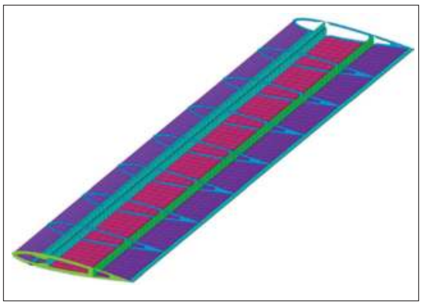
Morphing wing structure with controllable twist based on adaptive bending–twist coupling

Wolfram Raither[1], Matthias Heymanns[1], Andrea Bergamini[2] and Paolo Ermanni[1]

[1] ETH Zürich, Centre of Structure Technologies, Zürich, Switzerland
[2] Empa, Mechanics for Modelling and Simulation, Dübendorf, Switzerland

Abstract
A novel semi-passive morphing airfoil concept based on variable bending–twist coupling induced by adaptive shear center location and torsional stiffness is presented. Numerical parametric studies and upscaling show that the concept relying on smart materials permits effective twist control while offering the potential of being lightweight and energy efficient. By means of an experimental characterization of an adaptive beam and a scaled adaptive wing structure, effectiveness and producibility of the structural concept are demonstrated.

2013 *Smart Mater. Struct.* **22** 065017



Inner structure of the airfoil.

Compliant bistable mechanism for low frequency vibration energy harvester inspired by auditory hair bundle structures

Gi-Woo Kim[1] and Jaehwan Kim[2]

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[2] Department of Mechanical Engineering, Inha University, Incheon, Korea

Abstract
This paper presents a bio-inspired mechanism for the performance enhancement of piezoelectric power generation in vibration energy harvesting. A compliant bistable mechanism for vibration energy harvesting was explored based on the negative stiffness inspired by the auditory hair bundle structures. The proposed mechanism consists of a compliant, four-bar linkage system to mimic the hair bundle structure inside an inner ear. Our initial prototype energy harvester demonstrates that the compliant bistable mechanism featuring negative stiffness outperforms the conventional vibration energy harvester in the infra-low frequency range (1–10 Hz).

2013 *Smart Mater. Struct.* **22** 014005

Various shape memory effects of stimuli-responsive shape memory polymers

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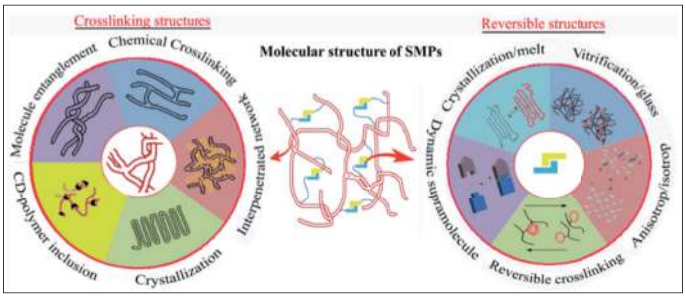
[2] Department of Mechanical and Industrial Engineering, Louisiana State University, Baton Rouge, USA

Abstract

One-step dual-shape memory polymers (SMPs) recover their original (permanent) shape upon small variation of environmental conditions such as temperature, electric field, light, magnetic field, and solvent/chemicals. For advanced applications such as aerospace and medical devices, complicated, multiple-step, spatially controllable, and two-way shape memory effects (SMEs) are required. In the past decade, researchers have devoted great effort to improve the versatility of the SME of SMPs to meet the needs of advanced applications. This paper is intended to review the up-to-date research endeavors on advanced SMEs. The problems facing the various SMPs are discussed. The challenges and opportunities for future research are discussed. Molecular structures of shape memory polymers. A stable network and a reversible switching transition are the prerequisites for the shape memory polymers to show shape memory effects.

2013 *Smart Mater. Struct.* **22** 093001



Molecular structures of shape memory polymers. A stable network and a reversible switching transition are the prerequisites for the shape memory polymers to show shape memory effects.

Design and fabrication of a bat-inspired flapping-flight platform using shape memory alloy muscles and joints

Stephen J Furst[1], George Bunget[2] and Stefan Seelecke[1]

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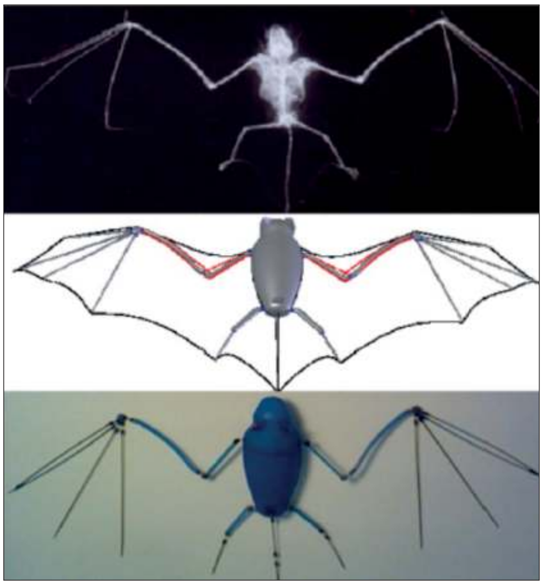
[2] Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleich, USA

Abstract

This work focuses on the development of a concept for a micro-air vehicle (MAV) based on a bio-inspired flapping motion that is generated from integrated smart materials. Since many smart materials have their own biomimetic characteristics and the potential to be highly efficient, lightweight, and streamlined, they are ideal candidates for use in structural or actuator components in MAVs. In this work, shape memory alloy (SMA) actuator wires are used as analogs for biological muscles, and super-elastic SMAs are implemented as flexible joints capable of large bending angles. While biological organisms have an intrinsic sensing array composed of nerves, the SMA wires also provide self-sensing by virtue of a phase-dependent resistance change. Study of the biology and flight characteristics of natural fliers concluded that the bat provides an ideal platform for SMA muscle wires because of its comparatively low wingbeat frequency and superb maneuverability. A first-generation prototype is built to further the understanding of fabricating Nature's designs. The engineering design is then improved further in a second-generation prototype that combines 3D printing and new techniques for embedding SMA wires and shaping SMA joints for improved robustness, reproducibility, and lifetime. These prototypes are on display at the North Carolina Museum of Natural Science's Nature Research Center, which has the goal of bridging the gaps between biology and engineering.

2013 *Smart Mater. Struct.* **22** 014011



Progression of the flapping platform from biological inspiration to 3D model then first-generation prototype.

Semi-active magnetorheological refueling probe systems for aerial refueling events

Young-Tai Choi and Norman M Wereley

Department of Aerospace Engineering, University of Maryland, College Park, USA

Abstract

This study analyzes the feasibility of applying a semi-active magnetorheological (MR) damper to a naval hose–drogue based aerial refueling system to minimize undesirable hose–drogue vibrations. The semi-active smart aerial refueling probe system consists of a probe, a coil spring, and a MR damper. The dynamics of the smart refueling probe system were derived and incorporated into an analysis of the coupled hose–drogue dynamics, so as to evaluate the load reduction of the refueling hose at the drogue position effected by the MR damper. The simulated responses of the smart refueling probe system using a MR damper were conducted at different maximum closure velocities of 1.56 and 5 ft s^{-1} and different tanker flight speeds of 185 and 220 knots. The simulations demonstrate that the smart refueling probe system using a MR damper enables large reductions in probe-and-drogue motions, as well as preventing the onset of large and undesirable hose–drogue motions resulting from tension loads during engagement of the probe.

2013 *Smart Mater. Struct.* **22** 092001

Metamaterial-inspired structures and concepts for elastoacoustic wave energy harvesting

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[2] G W Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, USA

Abstract
Enhancement of structure-borne wave energy harvesting is investigated by exploiting metamaterial-based and metamaterial-inspired electroelastic systems. The concepts of wave focusing, localization, and funneling are leveraged to establish novel metamaterial energy harvester (MEH) configurations. The MEH systems transform the incoming structure-borne wave energy into electrical energy by coupling the metamaterial and electroelastic domains. The energy harvesting component of the work employs piezoelectric transduction due to the high power density and ease of application offered by piezoelectric materials. Therefore, in all MEH configurations studied in this work, the metamaterial system is combined with piezoelectric energy harvesting for enhanced electricity generation from waves propagating in elastic structures. Experiments are conducted to validate the dramatic performance enhancement in MEH systems as compared to using the same volume of piezoelectric patch in the absence of the metamaterial component. It is shown that MEH systems can be used for both broadband and tuned wave energy harvesting. The MEH concepts covered in this paper are (1) wave focusing using a metamaterial-inspired parabolic acoustic mirror (for broadband energy harvesting), (2) energy localization using an imperfection in a 2D lattice structure (for tuned energy harvesting), and (3) wave guiding using an acoustic funnel (for narrow-to-broadband energy harvesting). It is shown that MEH systems can boost the harvested power by more than an order of magnitude.

2013 *Smart Mater. Struct.* **22** 065004

Kirigami artificial muscles with complex biologically inspired morphologies

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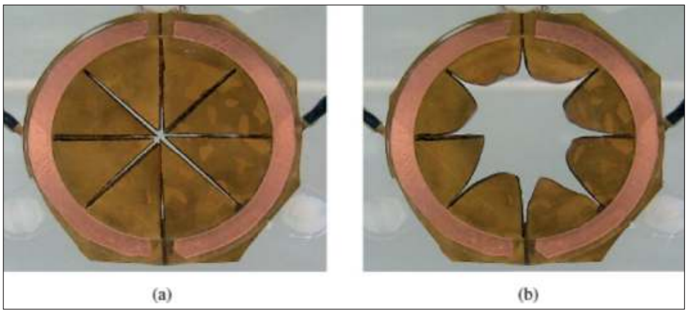
Abstract
In this paper we present bio-inspired smart structures which exploit the actuation of flexible ionic polymer composites and the kirigami design principle. Kirigami design is used to convert planar actuators into active 3D structures capable of large out-of-plane displacement and that replicate biological mechanisms. Here we present the burstbot, a fluid control and propulsion mechanism based on the atrioventricular cuspid valve, and the vortibot, a spiral actuator based on *Vorticella campanula*, a ciliate protozoa. Models derived from biological counterparts are used as a platform for design optimization and actuator performance measurement. The symmetric and asymmetric fluid interactions of the burstbot are investigated and the effectiveness in fluid transport applications is demonstrated. The vortibot actuator is geometrically optimized as a camera positioner capable of 360° scanning. Experimental results for a one-turn spiral actuator show complex actuation derived from a single degree of freedom control signal.

2013 *Smart Mater. Struct.* **22** 014004



Front view of the burstbot before excitation (a), and during excitation at 2 V (b).

Ten-year monitoring of high-rise building columns using long-gauge fiber optic sensors

B Glisic[1], D Inaudi[2], J M Lau[3] and C C Fong[3]

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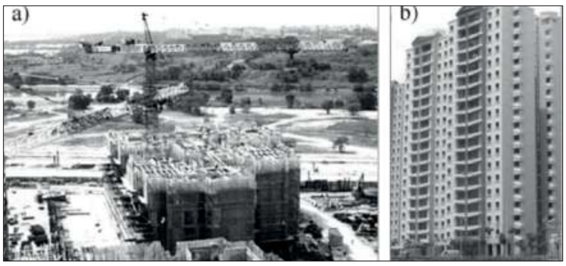
[2] SMARTEC SA, Manno, Switzerland

[3] Housing and Development Board (HDB), Singapore

Abstract
A large-scale lifetime building monitoring program was implemented in Singapore in 2001. The monitoring aims of this unique program were to increase safety, verify performance, control quality, increase knowledge, optimize maintenance costs, and evaluate the condition of the structures after a hazardous event. The first instrumented building, which has now been monitored for more than ten years, is presented in this paper. The long-gauge fiber optic strain sensors were embedded in fresh concrete of ground-level columns, thus the monitoring started at the birth of both the construction material and the structure. Measurement sessions were performed during construction, upon completion of each new story and the roof, and after the construction, i.e., in-service. Based on results it was possible to follow and evaluate long-term behavior of the building through every stage of its life. The results of monitoring were analyzed at a local (column) and global (building) level. Over-dimensioning of one column was identified. Differential settlement of foundations was detected, localized, and its magnitude estimated. Post-tremor analysis was performed. Real long-term behavior of concrete columns was assessed. Finally, the long-term performance of the monitoring system was evaluated. The researched monitoring method, monitoring system, rich results gathered over approximately ten years, data analysis algorithms, and the conclusions on the structural behavior and health condition of the building based on monitoring are presented in this paper.

2013 *Smart Mater. Struct.* **22** 055030



Building at Punggol EC26: (a) during construction and (b) upon completion.

Morphing structures using soft polymers for active deployment

Stephen Daynes[1], Amy Grisdale[2], Annela Seddon[3] and Richard Trask[2]

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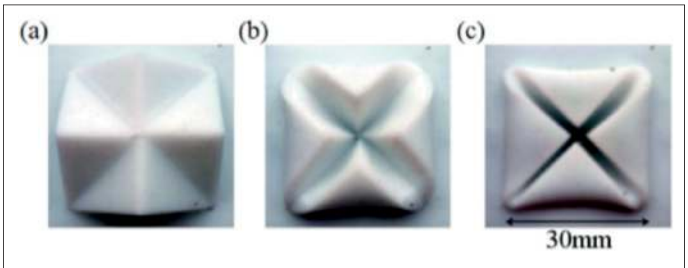
[2] Advanced Composites Centre for Innovation and Science, University of Bristol, UK

[3] Bristol Centre for Functional Nanomaterials, Centre for Nanoscience and Quantum Information, University of Bristol, UK

Abstract

In this study, we take inspiration from morphing strategies observed in nature, origami design and stiffness tailoring principles in engineering, to develop a thin walled, low cost, bistable cell geometry capable of reversibly unfolding from a flat configuration to a highly textured configuration. Finite element analysis was used to model the cell deployment and capture the experimentally observed bistability of the reinforced silicone elastomer. Through the combination of flexible elastomers with locally reinforced regions enables a highly tailorable and controllable deployment response. These cells are bistable allowing them to maintain their shape when either deployed or retracted without sustained actuation. It is proposed that such deployable cells with reversible surfaces and texture change can be used as a means of adaptive camouflage.

2014 *Smart Mater. Struct.* **23** 012001



Geometries of paper reinforced cell subject to a central vertically applied load: (a)–(c) manufactured sample at various stages of deployment.

An IPMC-enabled bio-inspired bending/ twisting fin for underwater applications

Viljar Palmre[1], Joel J Hubbard[2], Maxwell Fleming[2], David Pugal[1], Sungjun Kim[1], Kwang J Kim[1,3] and Kam K Leang[2]

[1] Active Materials and Processing Laboratory, Mechanical Engineering Department, University of Nevada–Reno, USA

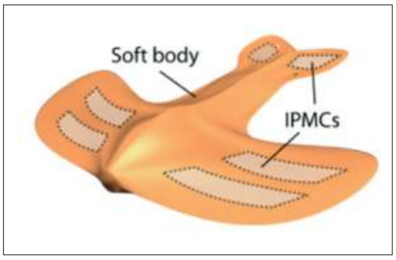
[2] Electroactive Systems and Controls Laboratory, Mechanical Engineering Department, University of Nevada–Reno, USA

[3] Mechanical Engineering Department, University of Nevada–Las Vegas, USA

Abstract

This paper discusses the design, fabrication, and characterization of an ionic polymer–metal composite (IPMC) actuator-based bio-inspired active fin capable of bending and twisting motion. It is pointed out that IPMC strip actuators are used in the simple cantilever configuration to create simple bending (flapping-like) motion for propulsion in underwater autonomous systems. However, the resulting motion is a simple 1D bending and performance is rather limited. To enable more complex deformation, such as the flapping (pitch and heaving) motion of real pectoral and caudal fish fins, a new approach which involves molding or integrating IPMC actuators into a soft boot material to create an active control surface (called a 'fin') is presented. The fin can be used to realize complex deformation depending on the orientation and placement of the actuators. In contrast to previously created IPMCs with patterned electrodes for the same purpose, the proposed design avoids (1) the more expensive process of electroless plating platinum all throughout the surface of the actuator and (2) the need for specially patterning the electrodes. Therefore, standard shaped IPMC actuators such as those with rectangular dimensions with varying thicknesses can be used. One unique advantage of the proposed structural design is that custom shaped fins and control surfaces can be easily created without special materials processing. The molding process is cost effective and does not require functionalizing or 'activating' the boot material similar to creating IPMCs. For a prototype fin (90 mm wide × 60 mm long × 1.5 mm thick), the measured maximum tip displacement was approximately 44 mm and the twist angle of the fin exceeded 10°. Lift and drag measurements in water where the prototype fin with an airfoil profile was dragged through water at a velocity of 21 cm s^{-1} showed that the lift and drag forces can be affected by controlling the IPMCs embedded into the fin structure. These results suggest that such IPMC-enabled fin designs can be used for developing active propeller blades or control surfaces on underwater vehicles.

2013 *Smart Mater. Struct.* **22** 014003



Example soft bio-inspired robotic platform with embedded IPMC actuators for controlled deformation of control surfaces.

Shape memory alloy wire-based smart natural rubber bearing

F Hedayati Dezfuli and M Shahria Alam

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Abstract

In this study, two types of smart elastomeric bearings are presented using shape memory alloy (SMA) wires. Due to the unique characteristics of SMAs, such as the superelastic effect and the recentering capability, the residual deformation in SMA-based natural rubber bearings (SMA-NRBs) is significantly reduced whereas the energy dissipation capacity is increased. Two different configurations of SMA wires incorporated in elastomeric bearings are considered. The effect of several parameters, including the shear strain amplitude, the type of SMA, the aspect ratio of the base isolator, the thickness of SMA wire, and the amount of pre-strain in the wires on the performance of SMA-NRBs is investigated. Rubber bearings are composed of natural rubber layers bonded to steel shims as reinforcement. Results show that ferrous SMA wire, FeNiCuAlTaB, with 13.5% superelastic strain and a very low austenite finish temperature (−62 °C), is the best candidate to be used in SMA-NRBs subjected to high shear strain amplitudes. In terms of the lateral flexibility and wire strain level, the smart rubber bearing with a cross configuration of SMA wires is more efficient. Moreover, the cross configuration can be implemented in high-aspect-ratio elastomeric bearings since the strain induced in the wire does not exceed the superelastic range. When cross SMA wires with 2% pre-strain are used in a smart NRB, the dissipated energy is increased by 74% and the residual deformation is decreased by 15%.

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Piezoresistive behavior and multi-directional strain sensing ability of carbon nanotube–graphene nanoplatelet hybrid sheets

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Abstract
Free-standing carbon nanomaterial hybrid sheets, consisting of multi-walled carbon nanotubes (MWCNTs), exfoliated graphite nanoplatelets (xGnPs) and nanographene platelets (NGPs) of different lengths and lateral dimensions, have been prepared using various material combinations and compositions. When subjected to tensile strains, the carbon nanomaterial sheets showed piezoresistive behavior, characterized by a change in electrical resistance with applied strain. Simultaneous measurement of resistance changes among multiple electrodes placed on the periphery of the hybrid sheets showed the dependence of resistance changes on strain direction, which potentially allows multi-directional strain sensing. Various combinations of MWCNT length, xGnP size and MWCNT-to-xGnP/NGP ratio result in different specific surface areas and nanoparticle interactions, which serve as critical factors for controlling the sensitivity of hybrid sheets. The smaller the nanoplatelet size and the higher the content as compared to MWCNT, the higher the sensitivity. Buckypapers, which are free-standing sheets composed of CNTs, are used as the control materials, and the unique characteristics of hybrid sheets are discussed.

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Electrets substituting external bias voltage in dielectric elastomer generators: application to human motion

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Abstract
Dielectric elastomer generators offer great potential for soft applications involving fluid or human interactions. These scavengers are light, compliant, have a wide range of functions and develop an important energy density. Nevertheless, these systems are passive and require an external bias source, namely a high voltage source and complex power circuits. This cumbersome polarization complexes the system in a drastic way and slows down the development of dielectric generators. In order to remove these problems, we propose here new transducers based on the use of an electret coupled with dielectric elastomer, thus avoiding the use of a high external voltage source, and leading to the design of a soft autonomous dielectric generator. By combining a dielectric model and the electret theory, an electromechanical model was developed to evaluate the capabilities of such a generator. This generator was then produced starting from Teflon™ as electret and silicone PolyPower™ as electroactive polymer. A good agreement between the model and the experiment were obtained. An experimental energy density of 0.55 mJ g^{-1} was reached for 50% strain (electret potential of −1000 V). Once optimized in its design, such a soft generator could produce energy density up to 1.42 mJ g^{-1}. An energy density of 4.16 mJ g^{-1} is expected with an electret potential of −2000 V.

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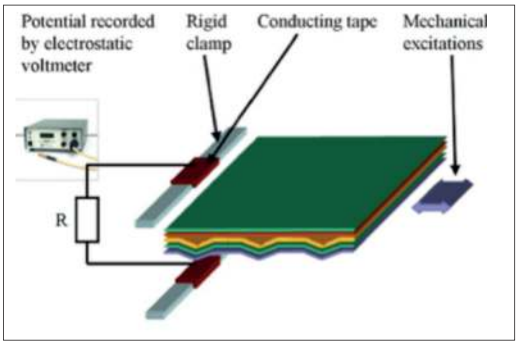

Dielectric elastomer generator.

Composite flexible skin with large negative Poisson's ratio range: numerical and experimental analysis

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Abstract
This paper describes the manufacturing, characterization and parametric modeling of a novel fiber-reinforced composite flexible skin with in-plane negative Poisson's ratio (auxetic) behavior. The elastic mechanical performance of the auxetic skin is evaluated using a three-dimensional analytical model based on the classical laminate theory (CLT) and Sun's thick laminate theory. Good agreement is observed between in-plane Poisson's ratios and Young's moduli of the composite skin obtained by the theoretical model and the experimental results. A parametric analysis carried out with the validated model shows that significant changes in the in-plane negative Poisson's ratio can be achieved through different combinations of matrix and fiber materials and stacking sequences. It is also possible to identify fiber-reinforced composite skin configurations with the same in-plane auxeticity but different orthotropic stiffness performance, or the same orthotropic stiffness performance but different in-plane auxeticity. The analysis presented in this work provides useful guidelines to develop and manufacture flexible skins with negative Poisson's ratio for applications focused on morphing aircraft wing designs.

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